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AN EXAMINATION OF THE SCIENCE LITERACY OF SCIENTISTS AND SCIENCE EDUCATORS

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ABSTRACT

This study develops a model for identifying and quantifying science literacy for the purpose of guiding science education policy and ultimately, resource allocation. The model is tested by attempting to distinguish groups who possess science literacy so as to identify their background and experiences that result in literate behavior. A survey of scientists and science educators provided data that show these groups 1) do not have high levels of content knowledge outside their area of professional expertise, 2) do not vote based on understandings of the scientific dimensions of public issues, 3) have significant beliefs in superstition and pseudoscience, and 4) make personal and social choices based on non-scientific aspects of decision-making situations. The author suggests that the pursuit of science literacy is an admirable but impractical goal and distracts resources that could be used to assure a well-prepared scientific work force that includes females and minorities.

INTRODUCTION

Science literacy is a term that is tossed about as if scientists and science educators agree or understand what it means. In researching literature to identify how the phrase is defined or even looking for consistent themes among definitions, one finds little, if any agreement. If science literacy is to be the goal (or even *a* goal) of science education then a model of literacy must be developed that can inform practice. It is the desire of this paper to suggest such a model and look at its implications for guiding practice.

To do this, this researcher first tried to examine and apply different existing models of science literacy to determine their implications for practice. Several definitions were used in this examination. Pella, et al. (1966), Harms & Yager (1981), Zimmerman (1990), Rutherford and Ahlgren (1990), Hazen and Trefil (1991), and the NSTA Position Statement on Science and Technology Literacy (1991) were all examined in a review of this literature. The NSTA position statement was used as

the basic definition because the elements of the other definitions could all be found within the NSTA definition.

> The NSTA position statement defines science and technological literacy as:
>
> The scientifically and technologically-literate person uses science concepts, process skills and values in making responsible everyday decisions; understands how society influences science and technology as well as how science and technology influence society; understands that society controls science and technology through the allocation of resources; recognizes the limitations as well as the usefulness of science and technology in advancing human welfare; knows the major concepts, hypotheses, and theories of science and is able to use them; appreciates science and technology for the intellectual stimulus they provide; understands that the generation of scientific knowledge depends upon the inquiry process and upon conceptual theories; distinguishes between scientific evidence and personal opinion; recognizes the origin of science and understands that scientific knowledge is tentative and subject to change as evidence accumulates; understands the applications of technology and the decisions entailed in the use of technology; has sufficient knowledge and experience to appreciate the worthiness of research and technological development; has a richer and more exciting view of the world as a result of science education; and knows reliable sources of scientific and technological information and uses these sources in the process of decision making.

To determine the practicality of this definition this researcher planned a series of surveys of scientists and science educators to determine how well they meet the definition of science literacy. To achieve this four key elements of the NSTA definition were used. 1) That literate persons use science concepts, processes and skills *in making everyday decisions*. 2) That literate persons knows *major concepts* and is able to use them. 3) That literate persons can *distinguish between scientific evidence and personal opinion*. 4) That literate persons *know reliable sources of information* and uses these sources.

The Surveys

Three surveys were conducted to test the science literacy of scientists and science educators and are reported elsewhere by this author. In the first project (Showers 1992), 82 scientists and science educators who attended a conference on reforming science education were surveyed. This survey looked at elements 1 and 3

described above. Showers (1992a) reported the results of two surveys—the first which looked at element 2 and the second that tested elements 3 and 4.

Science Literacy Survey

To test the idea that scientists and science educators use the concepts, processes and skills of science to make everyday decisions, several elements of the survey were used. When asked to give an example of an everyday decision s/he makes based on science concepts, processes or skills only 21 of the 82 provided any answer at all. Several of these were vague including "a number of issues", "equity for all peoples", and "abortion". Most of the remaining (12) cited consumer, medical, or nutrition decisions. When specifically asked how often s/he checks to see what additives are in the foods you consume, the respondents selected "Always or almost always" 14.6% of the time and "Often" 43.9 % of the time. This is higher that the levels reported by non-scientists.

Several other questions addressed rarer decisions, but ones that we are asked to make ever more frequently as members of an ever-more technological society. The first was to ask the subjects about their voting behavior. When asked, "Is there any scientific or technological issue that ever convinced you to vote for or against a candidate based on what you know about that issue?", 54 of the 82 responded "no".

When asked about locally unwanted land uses such as landfills, toxic waste or nuclear waste sites being built in their local areas, the subjects opposed these projects at the same rate as non-science members of the public at large. They were as likely to evacuate their homes during a nuclear plant emergency against expert scientific opinion as other citizens are. They are equally reluctant to submit to additional x-rays for medical diagnosis and equally likely to say they would take chemotherapy treatment for cancer for which there is no evidence that the treatment would be of benefit. In all of these cases above, it should be noted that these data are survey results and it should not be concluded that the subjects' behaviors would be expected to match their answers on a questionnaire with 100% accuracy. Still, the pattern of survey responses of the scientists and science teachers is consistent with

the pattern of responses given by non-scientists.

Another dimension of the everyday use of science concepts, processes and skills is in how an individual uses scientific attitudes and ways of thinking to influence personal beliefs. This is clearly the emphasis of Zimmerman's (1990) description of science literacy and but is also implied by others. The survey tested for this dimension by examining the holding of unscientific beliefs by those surveyed. One way in which this was done was to ask the subjects whether they believed in fifteen phenomena about which there is no scientific evidence. Data on the results of three of those questions are reported in Table 1.

Table 1

Responses of subjects regarding beliefs in selected phenomena.

Belief Topic	Teachers (percent believers) n = 43	Scientists (percent believers) n = 39	Total (percent believers) n = 82
ESP	55.0	48.7	53.7
Telekinesis	12.5	20.5	18.3

In addition, subjects were asked about their belief in the creation of the universe. The results of this question are included in Table 2.

Table 2

Responses to the question: I believe the creation of the universe a few thousand years ago by a Creator is:

Group	True	Probable	Possible	No evidence
Teachers	14	4	8	17
Scientists	12	0	8	19
Total	26	4	16	36

This researcher recognizes that using scientific ways of thinking does not mean that one must apply that thinking to every aspect of one's life. However, these data do reflect the levels of rejection of non-scientific concepts by members of the science and science education communities and therefore allows comparison between those groups and the general public. It can be hypothesized that levels of belief in phenomena that have no physical evidence nor any causal explanations

via current scientific theories would be less among science literate persons as defined by the NSTA position.

Radiation Principles Quiz

The second of the three surveys was to examine the knowledge of major science concepts. A quiz of ten questions was prepared dealing with fundamentals of radiation and the health effects of radiation. This topic was chosen because the concepts of radiation and its health effects relate to a wide variety of decisions in our technical society. Some examples include the siting of nuclear power plants and radioactive waste disposal facilities, decisions to have certain medical treatments, assessing the validity of claims in liability actions, and determining proper remediation of radon levels in homes and workplaces. This quiz was given to subjects from six target groups: nuclear engineering faculty, B.S. nuclear engineers, associate degree holders in nuclear technology, Ph.D. scientists in non-nuclear fields, secondary science teachers, and non-scientists. The results were as reported in Figure 1.

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INSERT FIGURE 1 ABOUT HERE

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The results lead to several conclusions. The quiz did examine *basic* concepts related to understanding radiation and radiation safety as evidenced by the fact that all of those in the nuclear-related education groups got all of the questions correct. Scientists knew more concepts than science teachers who demonstrated more knowledge than non-scientists. Even with respect to the prior conclusion, the practicing scientists only knew about 40% of this *basic* information about radiation. In addition, two of the non-nuclear scientists provided most of the correct answers for the group with scores of seven and eight on the quiz. Other data gathered showed that these individuals were biologists who used radioisotopes in their research and had training in radiation safety. The average in the group without these two was 31%, barely above the 29% of the non-science faculty.

Scientific vs Non-science Opinion Exercise

The third survey involved analyzing an issue of public debate with a scientific or technological basis. This study involved sending a copy of a guest editorial from *USA Today* to twenty college professors. Ten of these people were in science departments and ten were non-scientists. Each was asked to judge the editorial for errors of fact and errors of argument. Collectively, the group identified eight errors of fact and four errors of argument. In the science group, there was an average of 3.0 errors identified per person with a high of 6 and a low of zero. Among the non-science group, there was an average of 2.7 errors identified with a high of seven and a low of zero. These results are recorded in figure 2. In identifying errors of argument, the non-science faculty identified an average of 1.8 arguments with a high of 4 and a low of zero, while the science faculty identified an average of 1.6 errors with a high of four and a low of zero. These results are recorded in Figure 3.

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INSERT FIGURES 2 & 3 ABOUT HERE

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These findings are interesting in light of NSTA's recommendation that science literacy is, in part, about recognizing reliable sources of information. From this limited sample, these findings suggest that there are general critical thinking skills that are gained through a good education that make this recognition possible. It could therefore be suggested that science education itself is not a prerequisite to dealing with scientific issues in the public debate.

A Decision Making Model of Science Literacy

All of the discussion of science literacy is nothing but a Socratic debating exercise unless it has implications for practice. To do this, models for translating definitions into targets for instruction are needed.

As one reads and interprets the literature, one finds the most common model to be what may be called the "high jump model". This is when the author proposes

that there are only two levels of attainment, i.e. literate or illiterate, for an individual or for society as a whole. As most are familiar, these are the models that are reported in the popular press and many national reports decrying the lack of science literacy in the US. As examples Miller (1983) reports that 5 percent of all high school graduates are science literate and Shamos (1989) reports that 3% of all American adults are literate. The high jump model of science literacy is illustrated in Figure 4.

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INSERT FIGURE 4 ABOUT HERE

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The line on the graph that represents literacy may be set by research. The shape of this line may not be linear and hypothetically have several forms. The key element shown in the figure is that we expect as science experiences increase, as represented on the x-axis, that science literacy would increase. Once the shape of the literacy curve is determined empirically, it can be used to determine the kind of and level of experiences necessary to produce literacy among all citizens.

For example, if it is decided that 50 percent of some key concepts in radiation are needed by the general public for them to make acceptable decisions in our technological society, then we use the model to, in effect, "set the high bar." This is illustrated in Figure 5.

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INSERT FIGURE 5 ABOUT HERE

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After determining the acceptable level of public knowledge in a literate society, in this case 50% at Point A, the policy maker moves horizontally across the graph to intercept the literacy curve at Point B. On reaching the curve, s/he moves vertically down to intercept the x-axis at Point C. In the imaginary example given in Figure 5, this would mean that in order to attain the desired level of radiation knowledge literacy we would have to provide educational experiences o everyone

that are now only provided to those who go a little beyond high school.

Once the level of experience is set, we can now use the model to inform practice. If the goal is to have a literate society, where the society in general has the capacity to deal with technical issues, then the average performance or evaluation of the group must exceed the cutoff line. More likely, and in accordance with the definitions of science literacy now in use, we want to have every citizen scientifically literate as they all have an equal right to participate in democracy and to vote on issues. Therefore, if we want to produce literate individuals, if science literacy is a goal for all, then we must design programs and evaluations that help every student get above the high bar line and determine when they have gotten there.

To test this model, this researcher applied some of the data from the previously mentioned surveys along with some other existing data to try to produce curves like those described. Figure 6 represents the model applied to data on individual rejection of belief in psi. Psi is the concept that includes ESP and telekinesis. In 1988 the National Academy of Sciences reported that in over 3,000 studies conducted over 100 years that there was not one experimental result supporting the existence of psi. As shown in Table 2 earlier, 88% of the science teachers surveyed and 80% of the practicing scientists rejected belief in psi. Note: in order to be counted as rejecting psi, the individual only had to reject ESP belief or telekinesis belief. Psi belief was used rather than either of the individual phenomena to allow for comparison to the other two studies cited. In a Gallup poll (1988) it was reported that 83% of the general public rejects psi and Shore (1990) reported 96% rejection in a survey of NAS scientists. The NAS scientists were considered elite among practicing scientists and therefore at a level of experience clearly above the general body of practicing scientists. These data are displayed in Figure 6.

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INSERT FIGURE 6 ABOUT HERE

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This dynamic could then be used in making educational policy decisions. If reducing beliefs in pseudoscience is a concern in making Americans scientifically literate we must ask the question, What is an acceptable level of this belief? We must assume that we are not educating to eliminate belief *per se* but providing individuals with a scientific mind expecting them to reject such silliness. Also this is not a perfect world and even if rejection of superstition was the goal of education we must accept that it could not be achieved with 100% efficiency. If we are willing to allow one in five educated Americans to adhere to this paranormal nonsense, then we can see by the research that this has already been achieved. But if we should decide that we hope to lower the level of belief to 10 percent of the population, then we must give all citizens more experience with science than is currently provided to the average science teacher or practicing scientist. If we hope to reduce that further to one in twenty accepting psi, then all citizens must have the same collection of experiences as those currently experienced only by the most elite scientists.

In fact, the belated point of this exercise is to show how impractical high jump models of science literacy are. All of these models rely on the premise that all citizens need the same science literacy as all others. While supporting the liberal education of all students and the need for an informed electorate, it is an absolutely unobtainable goal to strive for some basic science literacy for all while ignoring the real impending challenges for science educators, namely providing all children with an education that allows the, *if they should so choose*, to enter fields of study and employment that require a knowledge of science, mathematics and technology.

It is indefensible to postulate that future English teachers, computer repair persons, clothing salespeople, nurses, historians, or contractors have any but the

most basic common need for science preparation. Some understandings of how diseases are transmitted, how babies best come into the world, nutritional information and some other health-type topics spring readily to mind. To justify expending more resources on the liberal science education of all, one should be able how to demonstrate how the illiterate lament for their lack of knowledge, e.g. how the otherwise well-prepared accountant suffers for not knowing the second law of thermodynamics as recommended in *Science Matters* (Hazen & Trefil, 1990). Wharton (1990) describes the coming "techno peasants" who will be doomed to lives of mundane jobs without science and mathematics education.

The informed electorate dealing with technological issues implies that educational systems including the media, libraries, Cooperative Extension, and so on, can provide citizens with technical information with which they will make up their minds about science-based issues before the public. This idea flies in the face of social psychological evidence about how people make such decisions. It would help public debate if everyone involved knew the difference between a scientific opinion and a personal belief. Quite often in the public debate if one holds college degrees in science or at least couches his or her arguments in scientific jargon, this is considered to be a scientific opinion. What these "debaters" and their followers do not know or choose to ignore is that a scientific opinion must demonstrate that it is falsifiable. At least the proposer must be prepared when asked to give the guidelines under which evidence might be presented which would lead to the rejection of his or her claim.

Where Should Science Educators Be Putting Their Efforts?

This researcher would propose that as science teachers, we are teachers first. As reported earlier, the ability to recognize insupportable claims was not a function of discipline, but one of critical thinking ability probably linked to educational level. During the Back to Basics movement there was an effort to describe science as "Reason, the fourth R". Now as then scientists and science educators try to usurp the use of evidence and logic as their own domain.

Many do not recognize the folly of this and its double dose of negative consequences. First, many scientists do not recognize that a great number of their own "scientific opinions" are really personal beliefs. If they gather evidence that supports their predetermined belief and reject counter-evidence they put themselves in the position that their conclusions are not falsifiable and therefore not scientific. Secondly, it is the stereotype that scientists are cold, rational, logical, calculating machines that turns off many prospective children to careers in science, technology and mathematics. And yet we deliberately foster those attitudes.

This researcher firmly believes that there are fundamental science concepts, skills and processes all educated citizens should experience in their education, formal and informal. In this area, though, I am a minimalist. The aforementioned health and nutrition topics and a couple of others will suffice. These can be taught and reinforced in a minimal amount of time during the thirteen years of school experience. What should drive the rest of the substantial, regular science program (including lessons every day in the elementary school) should be the interests and needs identified by the students. The emphasis would be on attitudes and process, not content. Attitudes, because a realistic view of how interesting science work is, how one does not have to be a male genius to do it and how it can lead to fascinating avocational pursuits makes it of most worth to the widest variety of children. The emphasis on process is because that's what children do best.

The Spectrum Model

If we are to abandon the high jump model of science literacy, what is to take its place? To be consistent with the principles that were used to critique the high jump model, any new model must be realistic and yet serve as an ideal. It must differentiate between the lifelong learning needs of people with different interests and yet meet the common needs of all as consumers, family members and citizens. Finally, it must inform practice—it must give us insights into how we can organize schools and curricula to achieve the tasks it sets out for us.

A model that can be adapted for this purpose already exists. Reading is the domain from which science borrowed the idea of literacy in the first place and it is to reading literacy that we may look for help. The National Assessment of Educational Progress (NAEP) measures the performance of students in a variety of subjects including reading. In doing so, students are identified by the kinds of tasks they are capable of doing with their reading. This assessment places readers into six levels, not the simple two of literate and illiterate.

Rudimentary literacy means one is capable of only simple tasks such as matching a descriptive phrase with a picture. At the *Basic* level one is able to understand information such as the facts of a news story. The basic level is attained by almost all 17-year-olds in America. *Intermediate literacy* is the ability to see the relationships among ideas and to generalize. *Adept literacy* demands that one understand, summarize and explain complicated information. *Advanced literacy*, which is attained by only about five percent of American adults, requires the reader to be able to synthesize and learn from specialized reading materials. This model is represented by the diagram shown in Figure 7.

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INSERT FIGURE 7 ABOUT HERE

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In a similar application, Rudimentary literacy in science could mean being able to avoid contracting diseases, producing a balanced diet if one so chooses, knowing fire and electrical safety and other immediate concerns that everyone is likely to encounter in one's lifetime. Basic literacy would further include knowing what the various subdisciplines of science study and some of the historical development of science. Here we would expect the development of a fundamental appreciation for the role of science in our society and understanding the nature, if not all of the details, of STS issues. Intermediate literacy would empower an individual at the avocational level. Hobbyists in electronics, radio operation, ecology, meteorology and astronomy would fall into this category. Some may be

quite accomplished in a particular field but probably still below the professionals in that field. Those professionals would delineate the adept level, those with preparation and experience that few nonprofessionals have the opportunity, nor perhaps the interest, to pursue. Finally, the advanced level would be long-time practitioners and philosophers of science. These would be the core of leadership that could guide the advancement of science and the society which relies on it.

The power of the spectrum model comes from the nature that it seeks to identify the kinds of science learners we want our system to produce. Students are therefore empowered to elect at one stage to seek Basic literacy and no more. Such a system of education would have to stress life long learning to make it easy for adults and non traditional learners to drop back in to pursue intermediate or adept literacy should their personal goals change.

CONCLUSIONS

The spectrum model of science literacy has great potential for informing practice and serving as a context for the reevaluation of science education. More work is needed to bring in expertise from laboratories, offices and classrooms to delineate the indicators that would give meaning to the different levels of the model. By abandoning the high jump model we can give up the vague feeling that more science, more process, more relevance, more of something will make people "better." By looking at different lifetime uses for science and meeting the learners needs we will ultimately meet the needs of society.

Finally, with no evidence to support it, this researcher believes this model will address the real crisis of science and technology, i.e. that young female and minority students chose not to participate. By the definition of basic literacy offered above, the goal of the science that all will have when they leave school is a realistic view of what science is and what scientists do. This model is based on relevance in the form of 1) using science to answer one's own immediate questions about the natural world and 2) addressing how science will fit into your future whether you today think you're going to be a hairdresser, cowboy, beekeeper, or nuclear engineer.

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Figure 1: Score on the radiation basics quiz by category

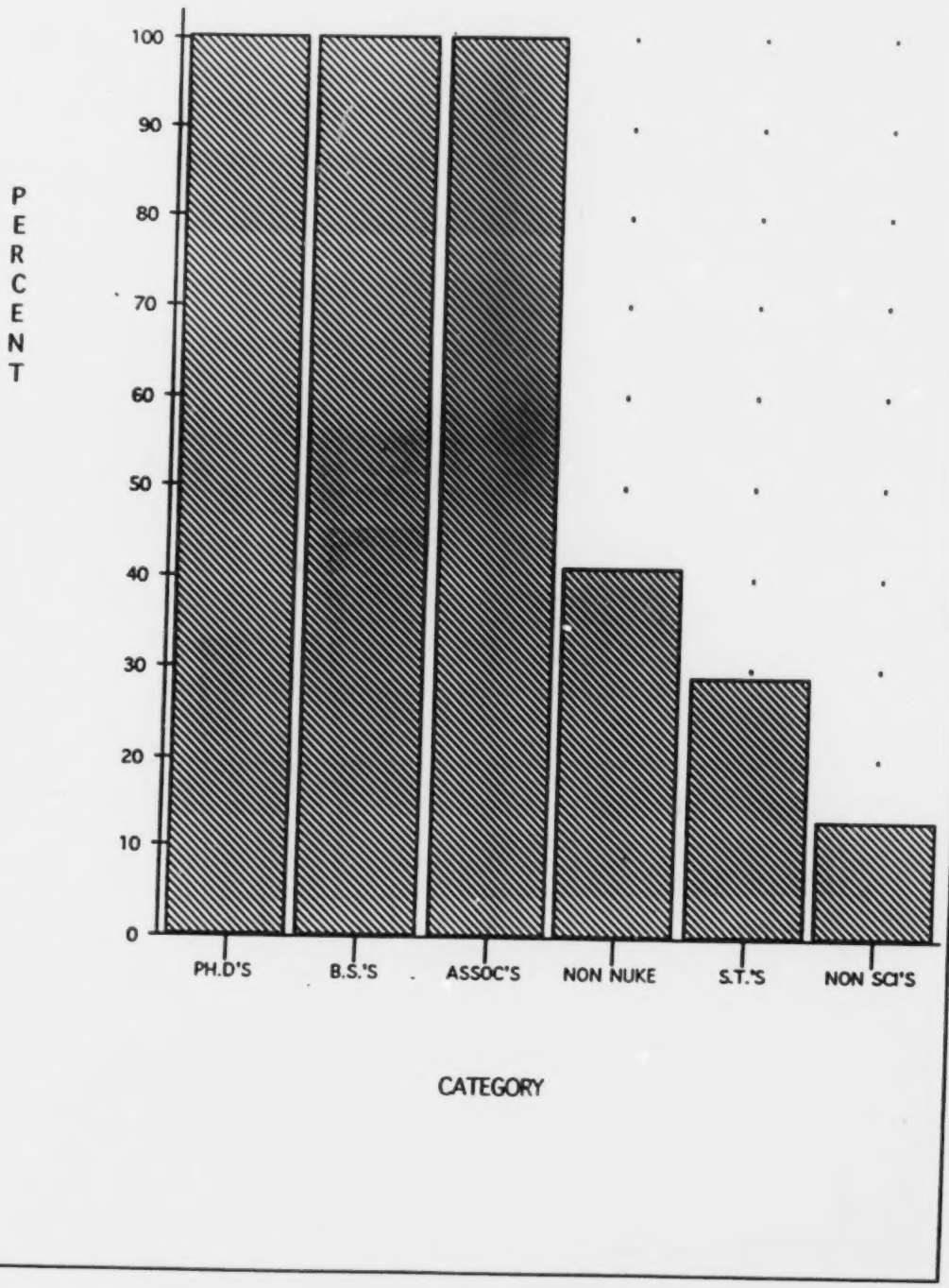

Figure 2: Comparison of the average number of errors of fact reported by science vs. non-science faculty

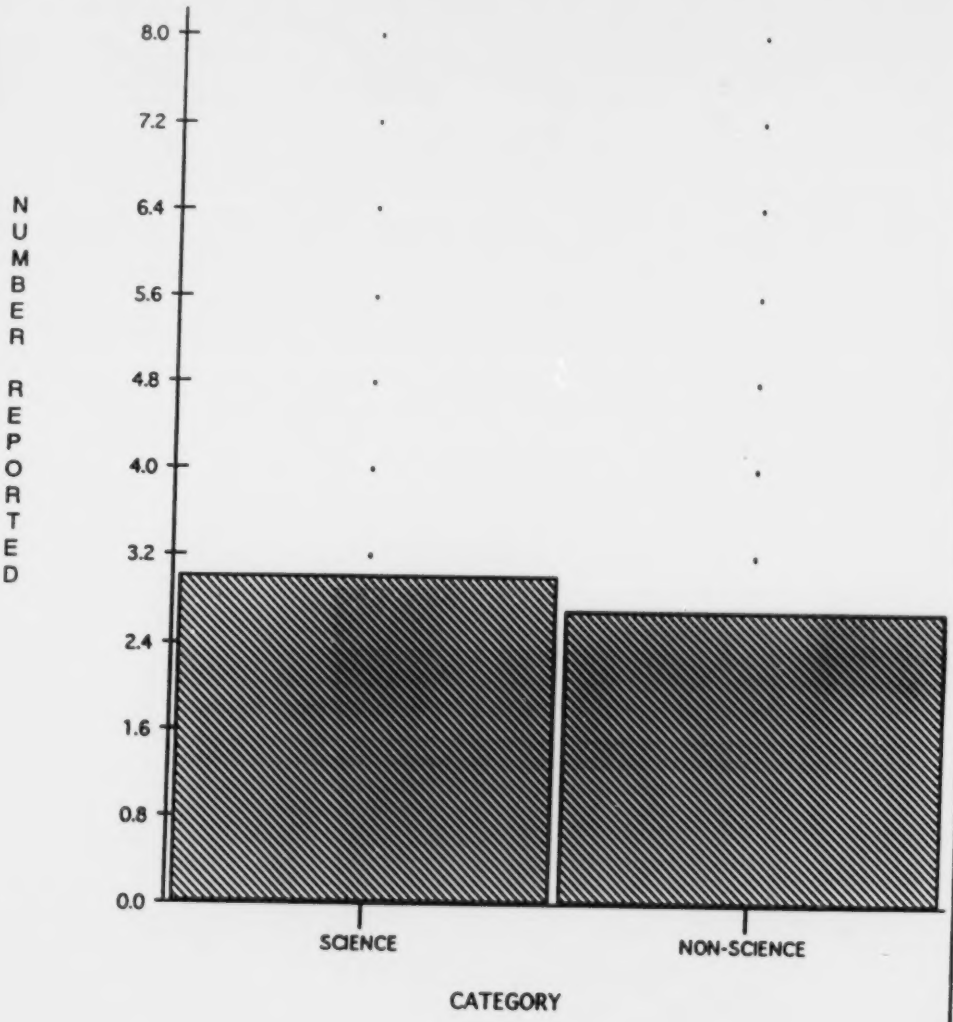

Figure 3: Comparison of the average number of errors of argument reported by science vs. non-science faculty

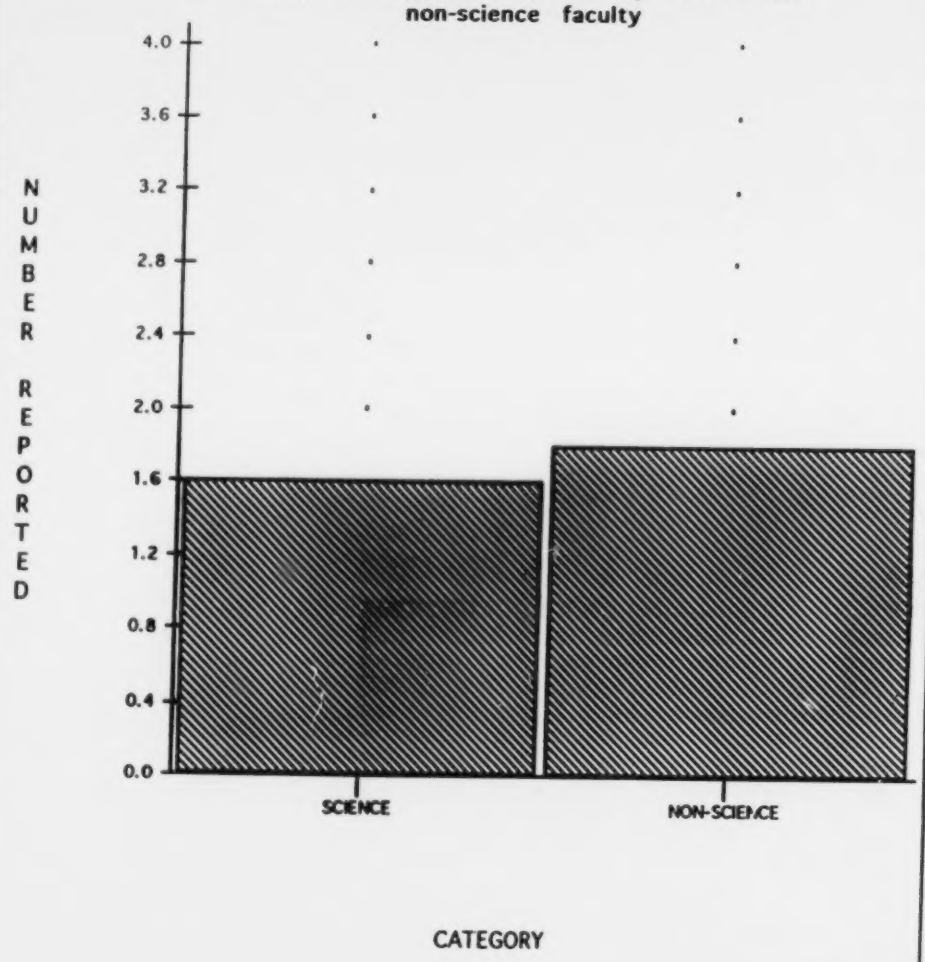

Figure 4
The "high jump" model of scientific literacy

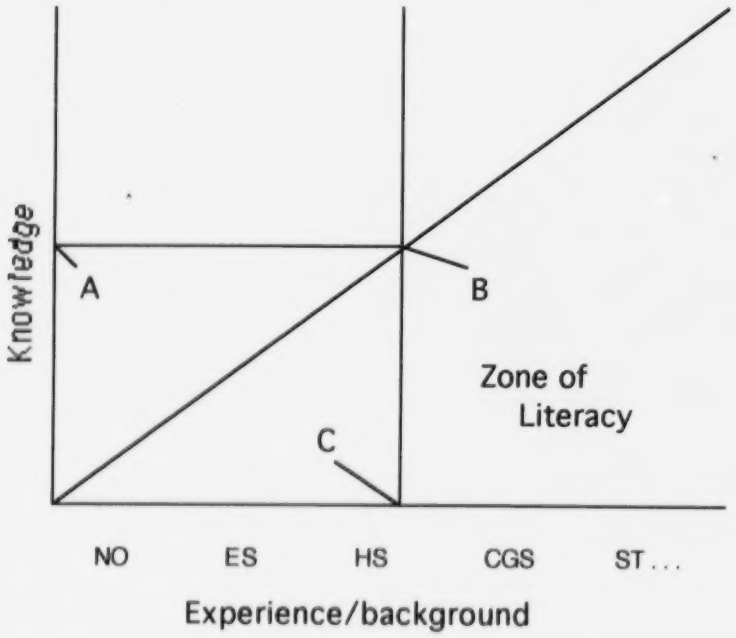

Figure 5
The model of scientific literacy applied to nuclear energy issues

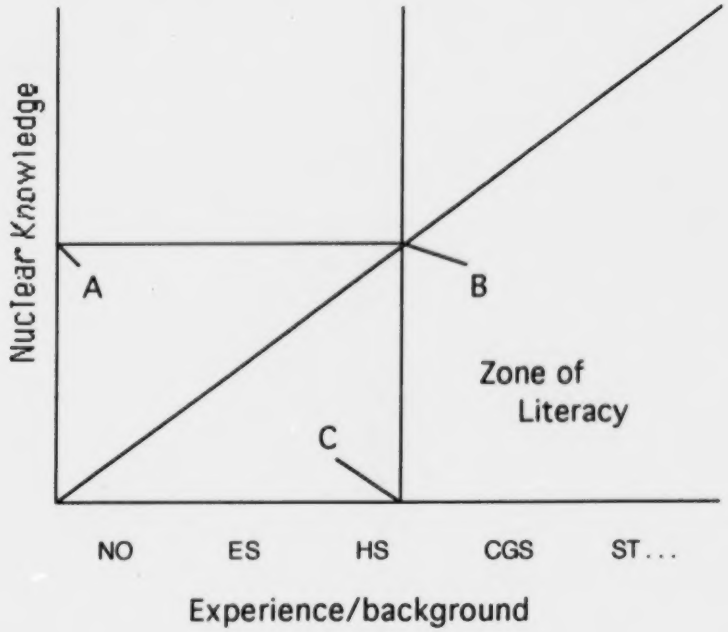

Figure 6

The model of scientific literacy applied to rejection of psi

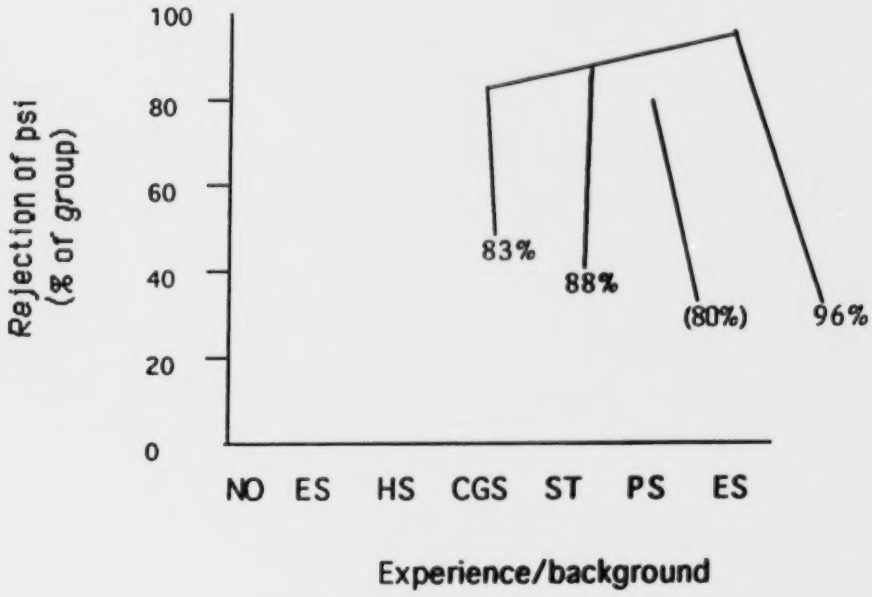

Figure 7
A multi-level model of reading literacy